ACOUSTICS

LECTURE 5

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Acoustical Requirements in Auditorium Design

Room Dimensions:

It is advisable to make one dimension of a room considerably larger than the others. The three dimensions should be neither too different from each other nor should they be equal. The general dimensions of a room depend on its shape. The preferred ratios of the room dimensions are given in the following table:

Table 3.1: The preferred ratios of room dimensions.

Type of room	Height (H)	Width (W)	Length (L)
Room < 200 seats	1	1.25	1.6
200 < Room < 500 seats	1	1.6	2.5
Room 500 seats	1	2.5	3.2
Room > 500 seats	1	1.25	3.2

Volume Per Seat:

The optimum volume per seat is dependent on both the seating capacity in the room and the purposes of the room.

The optimum volume per seat for a room is the lowest value consistent with the visual requirements, with the comfort of the audience and with the general appearance.

There are advantages of keeping the volume per seat at a low value as follows:

1- Building cost is greatly reduces.

2- Maintenance cost costs for lighting, cleaning, redecorating, air conditioning, etc… are correspondingly lowered.

3- Suppose that a given reverberation time is sought, the smaller the volume of the room the lower will be the units of absorption required to obtain this reverberation time.

In an auditorium with a low volume per seat, if the furnishings (seats, carpets, etc…) have been carefully chosen, there may be no need for additional acoustical materials to control the reverberation. Then the architect has a great freedom in his choice of materials for finishing the interior and for decoration.

Also, the sound level in a room for a source of a given power will be higher, as the volume per seat become smaller. In speech and music rooms where the sound amplification systems are not employed, this increased level is most beneficial. Even if a sound system is used, the smaller the room, the smaller will be the required power rating of the sound system.

The following table gives minimum, optimum and maximum value of volume per seat for different types of auditorium.

Type of auditorium	Volume per seat (m^3)		
	Minimum	Optimum	Maximum
Speech	2.3	3.1	4.3
Cinema	2.8	3.5	5.1
Theatre	5.1	7.1	8.5
Opera	4.5	5.7	7.4
Music	6.2	7.8	10.8

Table 3.2: The values of seats for different type of auditorium.

Example 3.1:

Calculate the suitable dimension of music hall with the capacity of 1000 audience.

Solution:

Room function is music

Optimum volume/seat = 7.8 m^3

Total volume of the room = volume/seat x capacity

= Product of ratio of dimension x X^3

Where X is the height of the auditorium

$\therefore 7.8 \times 1000 = (1 \times 1.25 \times 3.2) \times X^3$

$\therefore X^3 = 1950$

$\therefore X = 12.49$

$\therefore H = 12.49$ m   W = 15.61   L = 39.96

Room Shape:

The shape of a room has an important infulance on the quality of its acoustics. This should be remembered when the architect is designing a new room. The defects in its acoustics can often be avoided by giving the bounding surfaces their correct shape in the first place. If a defect is caused directly by the unsuitable shape of a room it will be very expensive if not impossible to remove the defect.

Hence, the determination of the most desirable shape is a problem that the architect should know how to solve.

Floor Plan:

The design of an auditorium or a lecturer room usually begins with the layout of the floor plans.

The sound level, especially in the higher frequency range, drops off rapidly at right angles to the direction of the speaker faces.

Hence, the front seats along the sides are not very satisfactory for hearing of speech in a large, square room, and these seats are usually outside of

the "beam" of the sound source. Owing to the high directionality of the human voice at high frequencies, it is necessary to place the audience within an angle of $\pm 45^{\circ}$ to the direction of the speaker faces.

Figure (3.1) shows a broad room and a narrow room, both of them are the same area. The speaker is placed at point S, and the hatched area is the useful seating area.

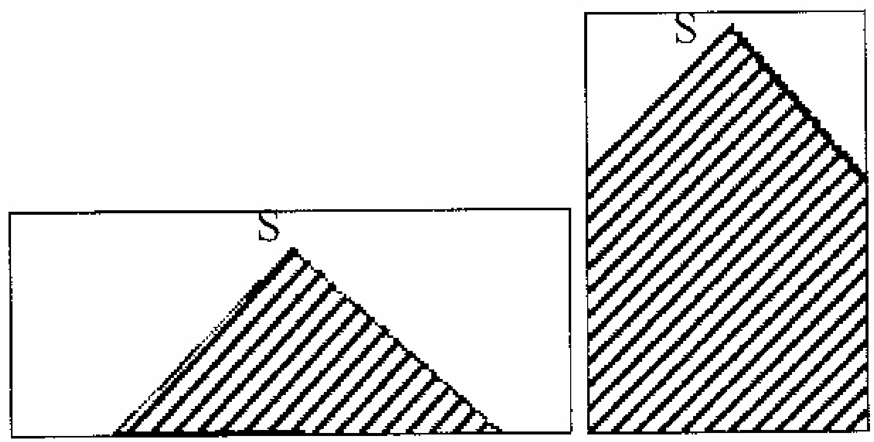


Figure (3.1): A broad and a narrow room.

Circular and elliptically shaped floor plans nearly always give rise to focusing effects, non uniform distribution of sound and echoes, see figure (3.2) and (3.3).

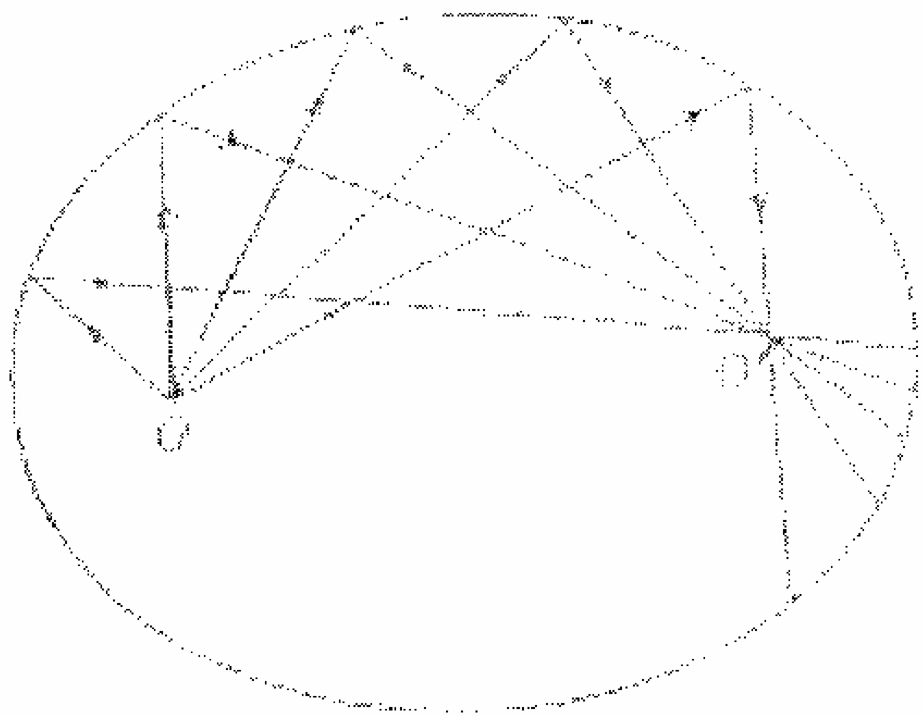


Figure (3.2): Elliptical floor plan illustrating an acoustical defect, focusing by the walls of the room.

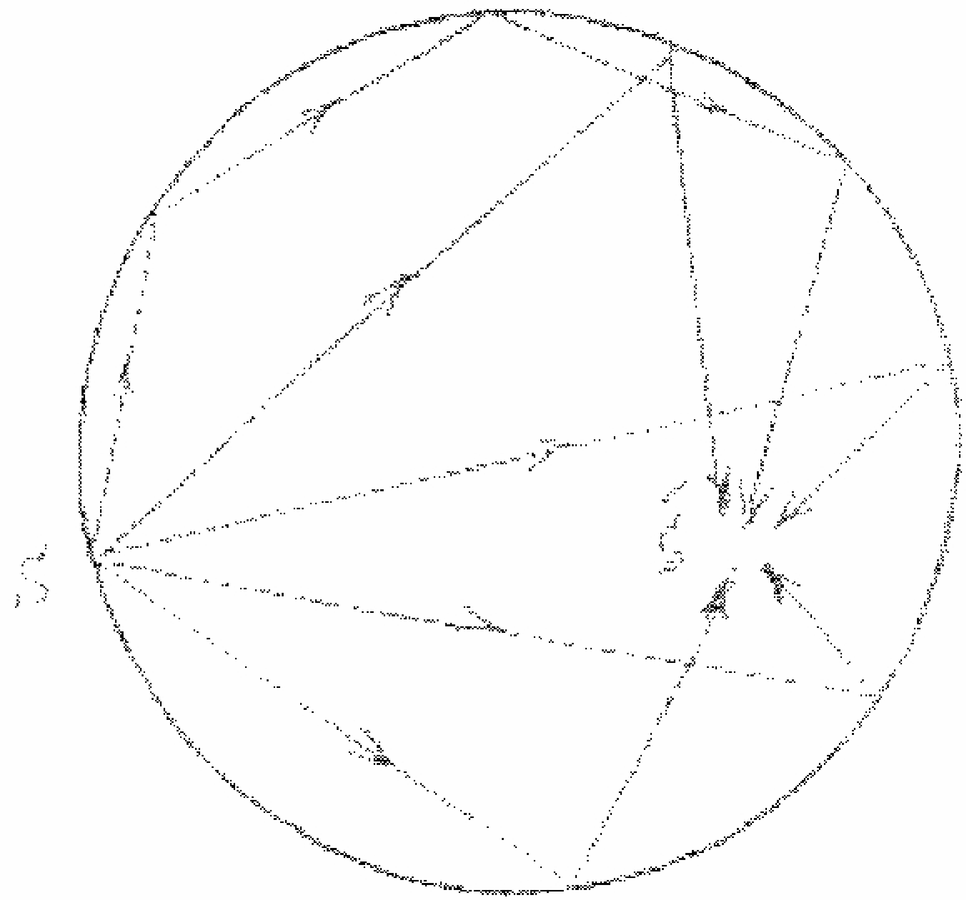


Figure (3.3): A circular plan illustrating two outstanding defects:

1- The tendency for sound to creep around the wall.

2- The focusing of sound due to reflection from the rear part of the circular wall.

In both elliptical and circular plans, the acoustical conditions can be greatly improved by the addition of cylindrical diffusing surfaces as shown in figure (3.4).

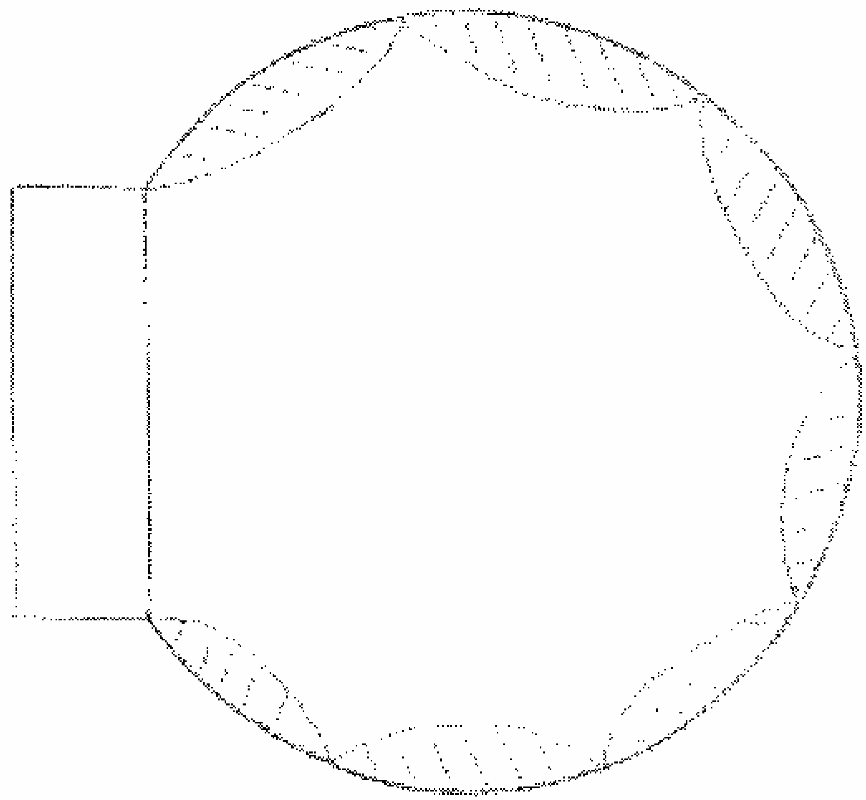


Figure (3.4): Circular flcor plan modified by convex diffusing surfaces, which greatly reduced by focusing and creeping effects.

In order to bring a large audience as close as possible to the stage of an auditorium, it is advantageous to design a floor plan with diverging side walls. Reflections from the walls can aid in the establishment of a higher sound level at the rear of the auditorium, but these reflections must be carefully controlled to prevent the occurrence of echo. It is good design to utilize the floor area, which has the best acoustical environment for seating and to use the poorest areas for non-listening purposes. Thus, wherever possible, the area directly in front of a speaker should be used for seating rather than for an aisle.

Ceilings:

The ceiling and walls should provide favorable reflections of sound especially for the seats far removed from the stage. In some instances, the ceiling also should aid in the diffusion of sound.

Lecturer rooms, music rooms and council chambers are types of rooms in which a low, smooth and highly reflective ceiling may be used to good advantage.

As shown in figure (3.5), ceiling splays in the front of a room can be advised to reinforce the sound reaching the rear parts of an auditorium. The law of reflection (angle of reflection = angle of incidence) can be used to determine the most suitable angle of inclination. Similarly, a splay between the ceiling and the rear can be designed to reinforce the sound at the rear of the room, and at the same time to prevent echoes from the rear wall.

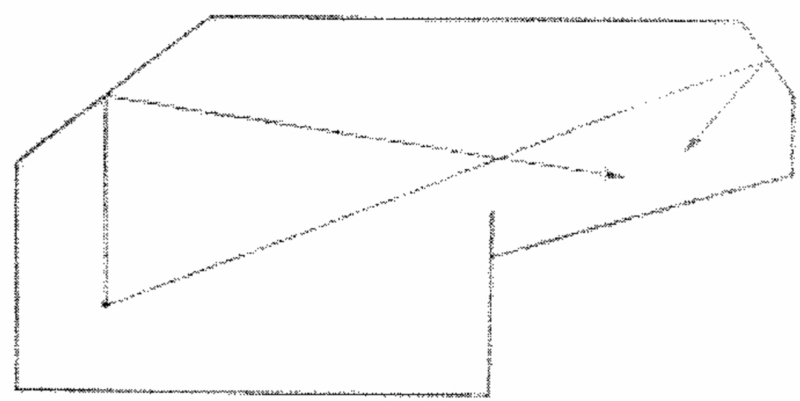


Figure (3.5): Ceiling splays in the front and rear of a room can be advised to reinforce the sound reaching the rear parts of an auditorium, the same time to prevent echoes from the rear wall.

Figures (3.6) and (3.7) show two type of different shapes of ceiling in the same type of theatre and give an indication of the reflection of sound waves from the ceiling.

The first shape causes echo and poor sound distribution.

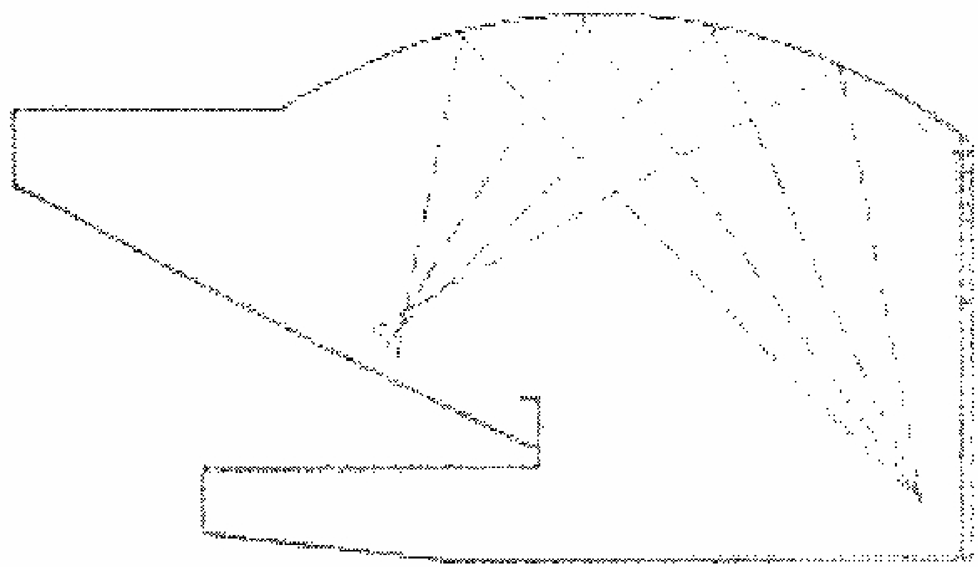


Figure (3.6): Ceiling shape causes echo and poor sound distribution.

The later helps to give a good distribution of sound over the seating area. The bottom of the balcony in the latter is shaped in such way that direct sound waves coming to the rear seats on the floor are reinforced by sound waves reflected from the bottom of the balcony.

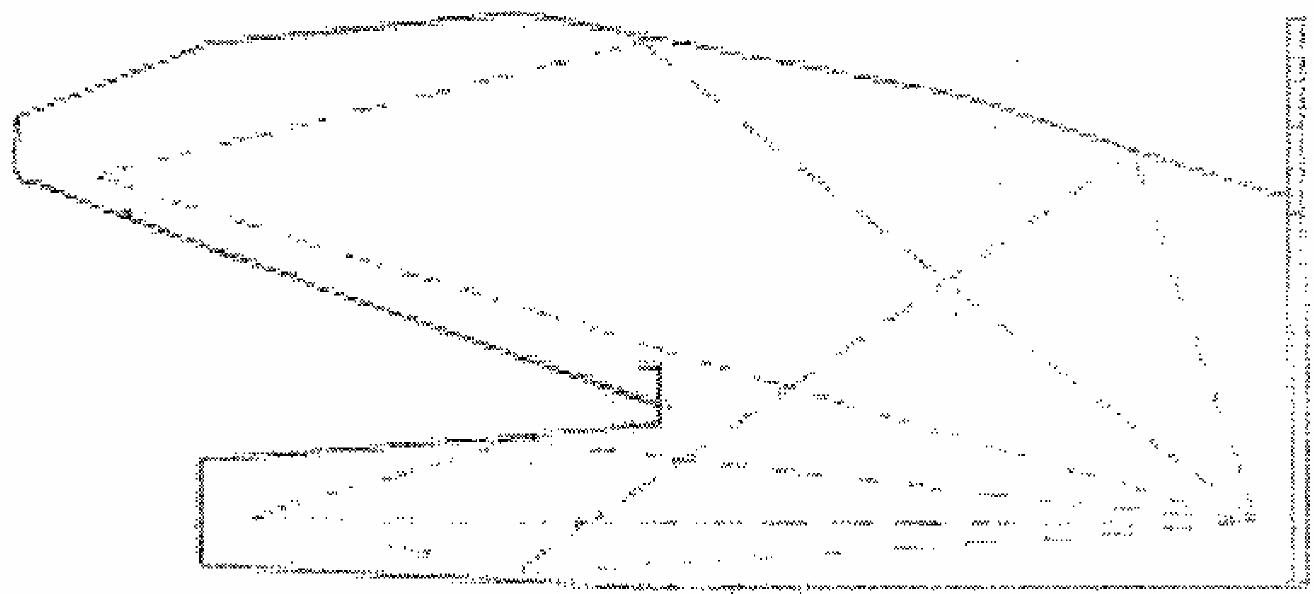
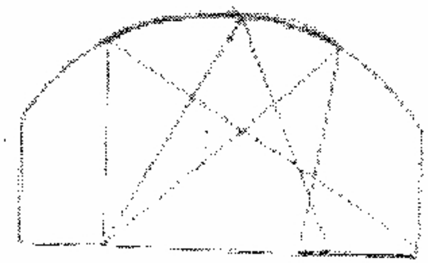


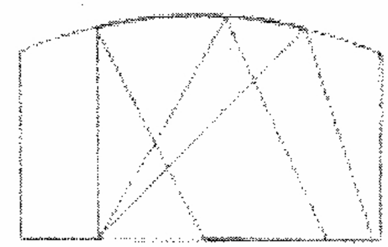
Figure (3.7): Ceiling helps to give a good distribution of sound over the seating area.

The depth under the balcony should not be greater than approximately 2 to 3 times the free height under the balcony front, the free height being the distance from the bottom of the balcony to the heads of audience. The sound level at the rear seats under the balcony will be insufficient if a greater depth is used.

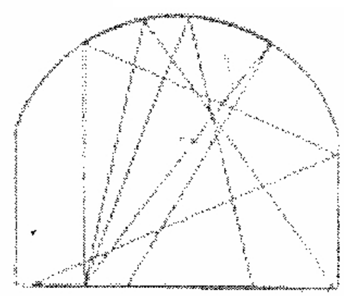
Concave surfaces such as domes should be avoided wherever possible. If they are required by the architectural style, the radius of curvature should be either at least twice the ceiling height, or less than one-half the ceiling height, see figure (3.8).



a. Radius of curvature equals the height.



b. Radius of curvature equals twice the height.



c. Radius of curvature equals half the height.

Figure (3.8): Radius of curvature of ceiling.

Rear Walls:

In the design of all rooms, large concave rear walls should be avoided. Walls with this shape are responsible for troublesome echoes and delayed reflections in many theaters and auditoriums.

By introducing a ceiling splay between the ceiling and the rear wall, as shown in figure (3.9), the distribution of sound waves at the rear seats can be improved.

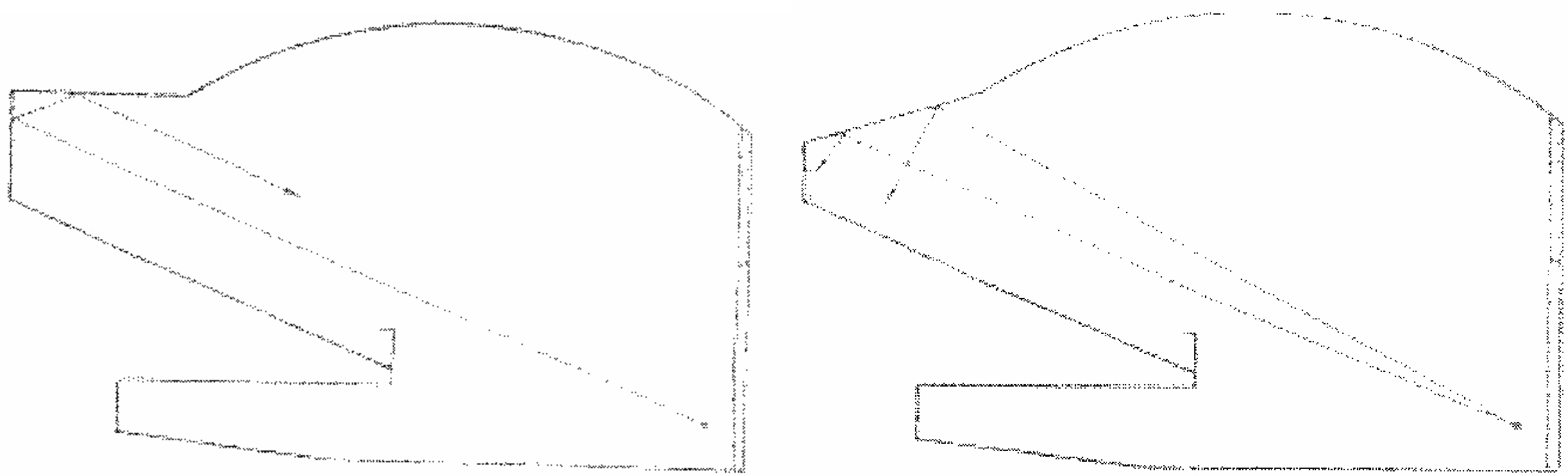


Figure (3.9): Reflection of sound from rear surfaces of an auditorium.

Elevation of Sound Source and Seats:

The audience constitutes a highly absorptive surface, and sound waves traveling just overhead will be considerably attenuated. The sound level due to direct sound will therefore be low on a great port of the setting area if the audience is placed on a flat floor. It is usual either to place the sound source high up, or to elevate the seats in order to provide a free flow of direct sound from the source to the audience.

Similar arrangements should be made when designing the platform of the musicians in a large orchestra. A suitable rake for the seats of the musicians ensures that the sound from the wind instruments will pass over the string instruments.

It is possible to lay down rules for designing a favorable rake of seats for the audience. In general the rake should be as steep as possible but it can also calculated on a scientific basis. The design for the rake in a room with a single sound source at a fixed place is given as an example. The notations shown in figure (3.10) are introduced.

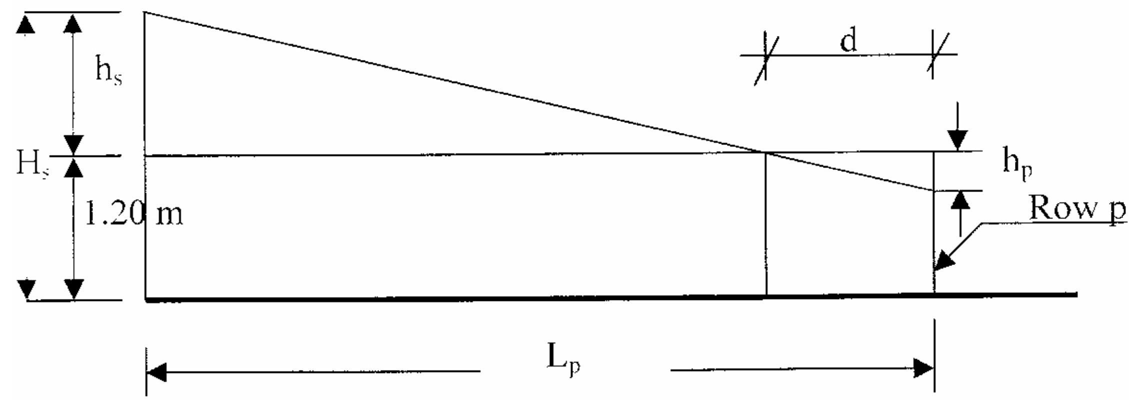


Figure (3.10)

In figure (3.10), H_s = height of the sound source above the horizontal part of the floor.

h_s = height of the sound source above the heads of the audience stead on the level floor (the height of the heads of a seated audience being about 1.20 m).

d = distance between two adjacent rows and should be more than 0.80 m.

L_p = distance from the sound source to row p on the level floor.

h_p = free height above row p.

The following equation has been constructed for calculating the value h_p:

$$h_p = H_s d / L_p$$

There should be a considerable free height if good listening conditions are to be obtained and it is advisable to make **$h_p > 0.12$ m.**

If the seats are staggered it is possible to reduce the requirements to **$h_p > 0.08$ m.**

The L_q distance between the sound source and the last row (row q) of the level floor before the raised floor should be used should never be more than the following:

$$L_q <= (H_s - 1.20)d/h_{ad}$$

Where h_{ad} is the advisable free height.

Example 3.2:

If Hs = 2.20 m & d=0.8m & had=0.08m

Calculate L_q

Solution:

$L_q <= (H_s - 1.20)d/h_{ad}$

$L_q <= 10m$

Audience at a greater distance than L_q from the sound source should be placed on raised seats.

تمت بحمد الله